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Casualty Estimates for ground burst 10 Megaton bombs

1956

Summary

Tentative estimates of casualties from up to 45 ground burst 10 megaton bombs on British cities are estimated for various conditions of shelter and evacuation.

Casualties from an attack aimed in the optimum way (to cause casualties) when there is no shelter or evacuation are found to range from over $2\frac{1}{2}$ million killed by a single bomb to just over half a million per bomb by 45 bombs. The total evacuation of the evacuation areas shown in Fig. 8 is found to reduce fatal casualties from this attack by from 99 to 84% depending on the number of bombs. Similarly the evacuation of the priority classes (45%) combined with the provision of a high standard of shelter for the remaining inhabitants of the evacuation areas would reduce fatal casualties from this attack by from 99 to 88% depending on the number of bombs. These are the maximum savings that could result from these policies. If the enemy adjusted his attack so that all his bombs were aimed at reception areas, thus achieving the maximum casualties among the evacuated and/or sheltered population, the reduction in fatal casualties would range from 62 to 44% for the policy of 100% evacuation, and from 79 to 65% for the policy of 45% evacuation combined with shelter. In the event of either of these policies being adopted the enemy would probably make some adjustments in his attack without going as far as in the limiting case above of aiming all his bombs at reception areas. The saving in casualties would then be intermediate between the two sets of figures given above.

Introduction

1. The object of the present paper is to arrive at the best possible estimate of the casualties from up to 45 ground burst 10 megaton bombs distributed in various ways over British cities so as to compare the effects of a number of possible shelter and evacuation policies. The extremely approximate nature of many of the assumptions on which this assessment is based must, however, be emphasised. Direct observational or experimental data are not available in many cases which means that the resulting estimates of casualties are liable to considerable errors. It might, in fact, be argued that the poor quality of the basic data does not justify the detailed methods adopted in this note. The advantages of the method are, however, that they enable the effect on the total casualties of each of the assumptions to be explored, and the estimates to be refined from time to time as fresh data become available. Moreover by setting out the assumptions in this way attention tends to be focussed on them, thus provoking criticism and discussion.

2. For a population under some sort of cover (i.e. not in the open) two of the four main effects of the explosion of megaton weapons dominate in producing casualties. These two effects are blast and radioactive fall-out. Of the other two effects heat flash, though a serious casualty producer among people in the open, will cause no direct casualties among a population under cover though it will produce a number of indirect casualties due to people being trapped in fires. Initial gamma radiation (and neutrons) will only cause casualties outside the range of blast

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casualties inside shelters with a very high blast resistance with a limited amount of overhead cover.

Casualties from radio-active fall-out

3. The shape and size of the fall-out pattern. The size and shape of the fall-out pattern for a ground burst 10 megaton bomb has been determined from the data presented at the February 1954 Tripartite conference*. The pattern consists of an ellipse with one apex at ground zero together with a circle centred a short distance down wind of ground zero. This pattern is reproduced as Figure 1 and the principal dimensions of some of its contours are shown in Table 1.

TABLE 1

Principal dimensions of fall-out pattern from ground-burst 10 megaton bomb with a 15 knot wind

Dose rate (r/hr at 1 hour)	Down wind length of ellipse (miles)	Cross wind width of ellipse (miles)	Radius of ground zero circle (miles)	Down wind displacement of ground zero circle (miles)
5000	23	5.5	2.6	1.5
3000	33	7	3.1	1.7
2000	45	8	3.6	1.9
1000	72	11	4.5	2.3
500	115	16	5.7	2.6
300	160	22	6.8	2.8

4. The wind speed of 15 knots for which contour dimensions are given in Table 1 and used throughout in this report is probably somewhat too low for the average U.K. "fall-out wind" (that is the vector mean wind over a height range from 0 to about 100,000 ft.). However contour areas are independent of wind speeds, so total casualties should be little affected by variations in wind speed.

5. The optimum time to leave a contaminated area. The total dose which the occupants of houses or shelters in a fall-out area receive will be made up of two parts - the dose they get while they stay in their house and the dose they get when they quit and cross the contaminated area. By leaving at the right time this total dose can be reduced to a minimum. The method of calculating this optimum time is given in the Appendix where it is shown to range between about 3 hours and one week depending on the protection available and the speed of travel out of the contaminated area.

6. Protective Factors of Houses. The fall-out protection provided by houses of different types varies over a very wide range, and this range is increased still further by the effects of blast damage. For undamaged

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* Since this study was started more recent U.S. data on fall-out patterns became available. These show a big reduction in dose rates close to ground zero, but it is not thought that the alterations in size and shape of dose rate contours of 3000 r/hr at one hour and less would be sufficient to invalidate the results of this study, but this point is further considered in paragraph 40.

/houses ....

houses with windows blocked the best data available are those from Guildford (CD/SA/75) and for the present study it will be assumed that the proportions of houses having different protective factors is the same for the whole country as it was found to be for Guildford. For purposes of computation the actual range of protective factors found at Guildford may be approximated as shown in Table 2.

TABLE 2

Protective factors of Guildford houses

Undamaged houses with windows blocked.

Percentage of houses	Protective factor
15	150
10	70
55	30
20	10

7. Effect of Blast Damage on protective factors. Consider a ground floor room of a typical 2 storey terraced house with 9 in. brick walls. This is found by the method of CD/SA.68 to have a protective factor (windows blocked) of 38. In experiments carried out at the Fuel Research Station* on the penetration of particles from a power station chimney (simulating fall-out) into a room with an open window, it was found that the average concentration inside the room was 14% of that outside.

8. If, due to blast damage of Category D to the house, all windows other than those of the refuge room are broken, then it will be assumed that 14% of the outside concentration of fall-out will get onto the first floor and into the ground floor room alongside the refuge room. This will reduce the protective factor of the refuge room to 23. The principal additional effect of C damage will be to let much of the contamination which would have lodged on the roof, through to the first floor. If it is assumed that the concentration on the roof and on the first floor is 50% of that outside and, as before, that 14% gets into the room alongside the refuge, then the protective factor falls to 14. For B damage the most realistic assumption seems to be 100% of the outside concentration on the first floor and 14% in the refuge room itself and in the room alongside. The protective factor is then 7.

9. Applying similar reasoning to the above to a basement under a 2 storey house, and to a 2 storey detached house we get the results summarised in Table 3.

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* D.S.I.R. Fuel Research Station Report Ref. D.F.R. 47/10/(a) "Measurement of Dust Deposition in a Room with an Open Window".

/ TABLE 3 ....

TABLE 3

Protective factors of damaged houses

Location of refuge room	Protective Factor			
	Undamaged	D damaged	C damaged	B damaged
Ground floor of 2 storey detached house	14	11	9	5
Ground floor of 2 storey terraced house	38	23	14	7
Basement under 2 storey house	150	38	30	10

10. The reductions in protective factors due to damage must now be applied to the range of protective factors shown in Table 2; the results of this are given in Table 4 which will provide the basis for estimating fall-out casualties in damaged houses.

TABLE 4

Assumed Percentages of damaged and undamaged houses having different protective factors

Percentage of houses	Protective Factor for damage category:-			
	Undamaged	D damaged	C damaged	B damaged
15	150	38	30	10
10	70	30	20	8
55	30	19	13	6
20	10	8	6	3

11. Stay in, and transit from a fall-out area. It will be realised from the Appendix that the length of time people stay in a fall-out area and their speed of transit when they leave it, vitally affect their total dose. Moreover their optimum time of stay is influenced by such factors as the surviving protection of their house, and their position in the fall-out pattern - factors which can certainly not be known by individuals in the fall-out area.

12. However for the purposes of calculating fall-out casualties some assumptions must be made, and those made for this study are summarised in Table 5.

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TABLE 5

Assumed times of arrival of fall-out, durations of stay and speeds of transit

Category of house damage	Time after burst of arrival of fall-out (T_1)	Duration of stay in refuge (T_2)	Speed of transit out of contaminated area (v)
Undamaged	2 hours	48 hours(1)	20 miles/hr(1)
D damage	½ hour	48 hours(2)	20 miles/hr(2)
C damage	¼ hour	Optimum(4) given by equation (2) of the Appendix. Actual range from 5 to 24 hours depending on protective factor of house.	2 miles/hr(3)
B damage	¼ hour	Optimum(4) given by equation (2). Actual range from 2½ to 9 hours.	2 miles/hr(3)

Notes of Table 5.

(1) In accordance with the proposals of the Provisional Scheme of Public Control in the fall-out area that the occupants of Zone Z should be evacuated by mechanical transport, starting 48 hours after the burst.

(2) There seems no reason why the above scheme should not operate in a D damaged area.

(3) Mechanical transport will probably not be able to penetrate into C and B damaged areas affected by heavy fall-out, and therefore transit on foot at 2 miles per hour is assumed.

(4) In practice these people might quit before the optimum time, or they might stay for the recommended 48 hours. In either case they would increase their dose. However leaving at the optimum time has been assumed for the present study since it leads to minimum casualties and ensures that the value of shelters will not be overestimated when casualties with and without shelters are compared.

13. Dose rate contours for death and sickness. The 50% lethal dose has been taken as 500 r and the 50% sickness dose as 200 r and it has been assumed that the number of people who survive a higher dose is equal to the number who die from a lower; that is to say it has been assumed that everyone who receives 500 r or more dies and everyone who receives less survives. This

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assumption would, of course, be correct in an area of uniform population density, but it may lead to a slight overestimate of casualties when the areas of higher dose rate tend to be more densely populated than those of lower. It is also realised that 500 r may be on the low side for the lethal dose when spread over a period of up to 48 hours. However no better figure is available.

14. Equation (1) of the Appendix and Tables 4 and 5 now enable the lethal and sickness contours to be calculated for the protective factors found in the various categories of damage, and these are given in Table 6.

TABLE 6

Dose rate contours for death and sickness

Category of damage	Percentage of houses	Protective factor	Dose rate contour (r/hr at 1 hr) for	
			Death	Sickness
Undamaged	15 10 55 20	150 70 30 10	(36,000)[x] (17,000) (7,000) 2,500	(14,000)[x] (7,000) 3,000 1,000
D damaged	15 10 55 20	38 30 19 8	5,400 4,300 2,700 1,200	2,200 1,700 1,100 500
C damaged	15 10 55 20	30 20 13 6	3,400 2,300 1,600 800	1,400 900 650 300
B damaged	15 10 55 20	10 8 6 3	1,300 1,000 800 500	500 400 300 200

15. The data given in Table 6 can now be combined with those given in Table 1 to produce a transparency showing the risk anywhere in the fall-out area, and this transparency can then be applied to a dot map of population distribution (each dot representing 1,000 people) to estimate casualties.

16. This risk transparency for death is reproduced as Figure 2. The use of this transparency to estimate casualties would however, entail a greater amount of labour than would be justified by the accuracy of the results, since the number of people in each of a number of small areas would have to be determined and then multiplied by the appropriate risk rate. A

x Dose rate contours given in brackets do not extend into the undamaged area.

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simpler procedure is to determine a dose rate contour (in each damage category) such that the area enclosed by it is equal to the product of the areas and risk rates shown in Figure 2. A number of trials showed that this dose rate contour could most accurately be represented by the geometric mean of the risk contours for each damage category, and the final death and sickness transparencies were therefore based on the dose rates shown in Table 7.

TABLE 7

Equivalent dose rate contours for 100% risk of death or sickness

Category of damage	Equivalent dose rate contour (r/hr at 1 hr) for 100% risk of:-	
	Death	Sickness
Undamaged	Nil. The 2,500 contour gives 20% risk	Nil. The 2,150 contour gives 75% risk
D damaged	2,700	1,100
C damaged	1,600	650
B damaged	800	300

17. In the case of death in undamaged houses it will be seen from Figure 2 that the highest risk is 20%, and that this occurs over a substantial area. Rather than represent this by an area of 1/5 the size with a 100% risk, it was considered more satisfactory to retain the larger area with its appropriate risk, since cases will occur where large towns would be covered by the 20% risk contour but missed by one covering only 1/5 of the area. Similarly for sickness when the highest risk in the undamaged area is 75%.

Combined Risk from blast and fall-out

18. For a population all in houses it has been estimated (1) that the "average circle" (2) radii of death and serious injury from a nominal bomb air burst at a height of $\frac{1}{8}$ mile are 0.6 and 0.7 miles respectively. Since these casualties are predominantly due to blast, we can obtain corresponding figures for blast casualties from a ground burst 10 megaton bomb by scaling them up to the distances at which corresponding blast pressures occur. These distances are approximately 4 and 5 miles, which will therefore be taken as the average circle radii of death and serious injury due to blast from a ground burst 10 megaton bomb.

19. Figs.3 and 4 show these "average circles" superimposed on the average lethal and sickness radiation contours (from Tables 1 and 7) around ground zero, to produce total death and sickness envelopes. The procedure adopted in preparing these envelopes should be clear from the Figures. In all cases

(1) CDJFS(EA)(50)4

(2) The average circle radius of death is defined as the radius of the circle which would contain all the fatal casualties if there were no deaths outside the circle and no survivors within it.

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the blast or fall-out radius, whichever is the greater, has been taken as the equivalent radius for the combined effects. This procedure must, of course, underestimate total casualties, since it ignores the fact that some of the survivors inside the 50% radius from one effect will be killed or injured by the other effect. However it would be difficult to allow for this enhancement effect, and ignoring it should have little effect on comparisons of casualties with different shelter and evacuation policies - the principal purpose of this paper.

20. A combination of Figs. 3 and 4 and Tables 1 and 7 now gives the final death and sickness envelopes, and these are shown in Figs. 5 and 6.

Population distribution with and without evacuation

21. Fig. 7 (not reproduced) shows the 1951 population distribution of the United Kingdom, each unit on the Fig. representing 1,000 persons. Casualty estimates have been made for 3 alternative evacuation policies:-

(a) No evacuation, distribution of population as shown in Fig. 7.

(b) Evacuation of the priority classes (45% of the population) from the evacuation areas recommended in CDJPS(EV)35*. A map showing these areas is reproduced as Fig. 8 and Table 8 summarises the numbers involved.

TABLE 8

Evacuation of Priority Classes

	Population (Millions)		
	Evacuation areas	Neutral areas	Reception areas
Pre-evacuation	25.6	3.7	19.6
Priority classes	11.5	-	-
Post evacuation	14.1	3.7	31.1

It will be seen that the population of the reception areas has been increased by a factor of 1.6. This factor was assumed to apply uniformly to all reception areas, and a revised population distribution map was prepared (Fig. 7a, not reproduced) with the population of the evacuation areas reduced by 45% and those of the reception areas increased by a factor of 1.6.

(c) Evacuation of 100% of the population from the above evacuation areas. It will be seen from Table 8 that this would involve moving 25.6 million persons and would increase the population of the reception areas by a factor of 2.3. A population distribution map (Fig. 7b, not reproduced) was also prepared for this scheme.

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* Since the work for this paper was started there has been some extension of the proposed neutral areas (CD(O)(56)5), but it is not thought that the alterations are sufficient to invalidate the conclusions of this paper.

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Distribution of Attack

22. An attack aimed at our centres of population in such a way as to achieve maximum casualties will also be very nearly the optimum attack for damage to general industry. Since the effects of fall-out are less certain than those of blast, it has been assumed that the enemy would choose his aiming points without regard to potential fall-out casualties which he would regard as a bonus. It has further been assumed that the enemy would base his choice of aiming points on a casualty radius of 5 miles; that is to say he would drop his bombs so as to maximise the number of people within 5 miles of a bomb. On this basis the 45 best aiming points in the United Kingdom, and the number of people within 5 miles of each, are listed in Table 9.

Casualty Estimates

23. The casualty envelopes (Figs. 5 and 6) must now be applied to the population distribution maps (Figs. 7, 7a and 7b) in the order given in Table 9. For this a wind direction of 281.5°, the average for the U.K. up to a height of 100,000 ft. over the whole year, was assumed. The resulting casualties for the three conditions of evacuation are given in Table 10. In general each successive bomb kills fewer people than the one preceding it, but there are a number of outstanding exceptions to this (e.g. bomb 19). This, of course, is because the bomb positions were chosen, and arranged in order, without regard to fall-out casualties. If the fall-out casualties had been taken into account in deciding the bomb order, there would have been a number of changes in the latter.

24. Another apparent anomaly in the table is that some bombs (e.g. No. 11) actually reduce the number of injured. This, of course, is because they fall in an area in which people had been injured by a previous bomb, in this case by the bomb on Manchester whose fall-out plume lay right across Sheffield, and convert those injured into killed.

25. It is clear from Table 10 that the 100% evacuation scheme achieves a spectacular reduction in casualties, e.g. for a 20 bomb attack the killed are reduced from 18 million to just under 1 million. However, this is not an altogether fair comparison; if a policy of 100% evacuation had been implemented it must be assumed that the enemy would not continue to aim all his bombs at the main centres of population which had been totally evacuated. Just what he would do is uncertain, but it is of interest to estimate the casualties that would result from the worst possible attack (from a casualty point of view) after a 100% evacuation had been carried out. The aiming points for this attack, and the casualties resulting from it, are given in Table 11, and the results are plotted in Fig. 9 together with those from Table 10. In practice, if a policy of 100% evacuation were carried out, it seems likely that the enemy's attack would be a compromise between the "standard" attack of Tables 9 and 10 and the "worst possible" attack (for this evacuation policy) of Table 11, and the casualties would then be intermediate between these two cases. It can then be concluded from Fig. 9 that a policy of priority evacuation would reduce casualties by a factor of nearly 2, and a policy of 100% evacuation by a further factor of about 2.

Effect of Shelter on Casualties

26. Assumed Shelter Provision Conversion in Evacuation Areas. It is assumed that the inhabitants left in evacuation areas (14.1 million) would be provided with tunnel shelters of the type discussed in CDPC(S)(51)15 at an estimated cost of £200 per person.

27. The exact distance at which these tunnels would fail from a ground burst 10 megaton bomb is uncertain, but the available data suggest that

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the lower limit for certain rupture in dry soil would be $\frac{1}{4}$ mile, and the upper limit for a chance of rupture in saturated soil would be $1\frac{1}{4}$ miles.

28. However the blast pressures at less than a mile from ground zero are so high (blast pressure at 1 mile = 200 lb./sq. in.) that even if the tunnel itself survived it would be difficult if not impossible to design blast doors to stand up much inside a mile. One mile is therefore considered to be a reasonable figure to take as the average circle radius of death for the occupants of tunnel shelters.

29. With tunnel shelters of the type under consideration there is clearly no need to worry about the effects of fall-out, since the occupants would always be able to travell along the system and emerge in an area free of fall-out.

30. Assumed Shelter provision in Neutral and Reception areas. Fall-out represents the principal threat to the inhabitants of neutral and reception areas and it is assumed that they would all be provided with fall-out shelter having a protective factor (if undamaged) of 150. Just how this could be done, and what it would cost, cannot be determined until the results of a fall-out shelter survey at present being planned are available. Its basis would probably be the maximum use of existing basements, the construction of underfloor trenches (WPSP(55)5) wherever possible, and the adaptation of suitable large buildings as communal shelters.

31. It is assumed that protective factors would be reduced by damage to the same extent as was shown in Table 3 for basements, that is to say protective factor undamaged = 150, D damaged = 38, C damaged = 30 and B damaged = 10.

32. Assuming the same durations of stay in shelter and speeds of transit as for houses (Table 5), results in dose rate contours for death or sickness as shown in Table 12.

TABLE 12

Dose rate contours for death or sickness

Emergency Shelters

Category of damage	Dose rate contour (r/hr at 1 hr) for	
	Death	Sickness
Undamaged	(36,000)+	(14,000)+
D damaged	5,400	2,200
C damaged	3,400	1,400
B damaged	1,300	500

\+ Dose rate contours given in brackets do not extend into the undamaged area.

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33. No data exist from which a firm estimate could be made of the blast radii for death and injury in the type of fall-out shelter discussed above. However they would clearly be better than houses, and arbitrary radii of 3 and 4 miles for death and serious injury will therefore be assumed. Combining these radii with the dose rate contours of Table 12 results in the envelopes for death and sickness shown in Figs. 10 and 11, and applying these envelopes to the population distribution map (Fig. 7) in the order which was found to be best for no shelter and evacuation (Table 9) gives the results listed in Table 13. As would be expected the earlier bombs, falling on areas provided with good shelters and from which 45% of the population have been evacuated, cause relatively few casualties. It is therefore of interest to compare these results with those of an attack designed to cause maximum casualties under the assumed conditions of shelter and evacuation, and the results of such an attack are given in Table 14. The results given in Tables 13 and 14 are plotted in Fig. 9 where they may be compared with the "no shelter" cases.

34. The results given in Fig. 9 are perhaps easier to appreciate in tabular form and Table 15 shows the percentage saving in fatal casualties resulting from various shelter and evacuation policies (for the attack given in Table 9 which, it will be remembered, was designed to cause mazimum blast casualties if there was no shelter or evacuation).

TABLE 15

Saving in fatal casualties with various shelter and evacuation policies (attack on centres of population)

No. of bombs	Percentage saving in killed		
	45% evacuation	100% evacuation	45% evacuation and shelter
5	44	98	96
10	44	98	96
15	44	95	94
20	44	94	94
30	43	90	91
40	40	84	88

35. It will be seen from Table 15 that 45% evacuation (the priority classes) saves very nearly 45% of casualties for the smaller numbers of bombs, the saving decreasing with increasing weight of attack. This is, of course, because with the heavier weights of attack more and more bombs fall in neutral or reception areas. 100% evacuation almost eliminates casualties for the lighter weights of attack but, for the same reasons as with 45% evacuation, the saving decreases with increasing weight of attack. 45% evacuation combined with shelter shows a slightly more consistent result - rather worse than 100% evacuation for small numbers of bombs and rather better for large numbers.

36. However as mentioned in paragraph 25 if either of the above policies were implemented the enemy would almost certainly make some changes in the distribution of his attack in order to increase casualties. The worst that he could do in this direction is summarised in Table 16 (attacks of Tables 11 and 14). In the event the attack would be unlikely to be entirely

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directed in this way against reception areas, and the actual saving in fatal casualties would be intermediate between the results of Tables 15 and 16.

TABLE 16

Saving in fatal casualties with various shelter and evacuation policies (worst possible attack)

No. of bombs	Percentage saving in killed	
	100% evacuation	45% evacuation and shelter
5	62	79
10	58	76
15	52	72
20	50	71
30	47	68
40	44	65

Effect on Casualties of Variations in the Assumptions

37. In arriving at the casualty estimates given in Tables 10, 11, 13 and 14 and in Fig. 9 a large number of assumptions have been made on such aspects as duration of stay in shelter, speed of transit out of fall-out area, protective factors of damaged and undamaged houses, etc. Since the values assumed for most of these parameters are little better than inspired guesses it is important to get some idea of their influence on casualties. This can most easily be done by examining the influence of each assumption on the area of the casualty envelope (Fig. 5). Admittedly an alteration in the area of the envelope close to ground zero will have a greater effect on casualties than a similar alteration further away, since population densities will, in general, decrease with distance from ground zero. However it should be satisfactory to compare changes in assumptions on the basis of the areas of the casualty envelopes provided that it is remembered that the proportionate increase or decrease in casualties will always be somewhat less than the corresponding increase or decrease in the area of the casualty envelope.

38. Table 17 shows the various alternative assumptions that have been tried out, and the effect of each of them on the total area of the lethality envelope (Fig. 5). Case 1 is, of course, the standard case of paragraphs 6-20 and the areas of lethality in the other cases have been compared with this as a standard.

39. Cases 2 and 3 show that the effect of a reduced duration of stay in shelter or of a reduced speed of transit out of the contaminated area are not very serious, the area of the lethality envelope being increased by only 6% in each case. When, however, these two effects are combined as in Case 4 the effect is somewhat more serious, the lethal area being increased by 29%.

40. Case 5 draws attention to the over riding importance of the assumptions which are made about the size and shape of the fall-out pattern. There can be no doubt that uncertainties on this score alone make all casualty estimates in this note subject to a large possible error - probably by a factor of at least 2 either way. However although absolute casualties may be out to this extent, the effect of uncertainties in the fall-out

/pattern ....

pattern on the comparison between one shelter or evacuation policy and another should not be anything like so serious.

41. Case 6 shows the effect of improved fall-out protection. The protective factors assumed for this case, 150 in undamaged houses falling to 38, 30 and 10 in D, C and B damaged houses respectively, are probably about the maxima that could be achieved in ordinary houses. Although the reduction in lethal area (26%) is substantial, it is not as great as might have been expected. It must be remembered that most fall-out deaths occur in areas of C and D damage (see Fig. 5). It follows that to achieve a large reduction in casualties, shelter that maintained a protective factor of the order of 100 even when the house was badly damaged by blast would be required. It does not seem possible to provide this in ordinary houses - whatever sort of refuge room is used its protective factor is bound to be substantially reduced when the house is opened up by blast.

42. However the value of fall-out refuges cannot be judged only by their effectiveness in reducing deaths. Their relative effectiveness in reducing sickness is considerably greater (46% instead of 26% in Case 6 of Table 17). This, of course, is because a greater proportion of sickness cases occur in areas of light damage or no damage when the protective factor is unaffected by blast. For the same reason, of course, the effectiveness of refuges in reducing the dose to the very large numbers of people who receive a less than sickness dose would be even greater.

E.L.W.
O.S.A. 42/8/6

1st October, 1956

Appendix.
Figures 1-6 and 8-11
attached.

TABLE 9

AIMING POINTS SELECTED TO MAXIMISE THE NUMBER OF PEOPLE WITHIN 5 MILES OF A BOMB

Bomb No.	Aiming Point	No. of people within 5 miles (1000's)	Cumulative total (1000's)
1	London (1)	2,478	2,478
2	London (2)	1,172	3,650
3	London (3)	1,133	4,783
4	London (4)	1,115	5,898
5	Glasgow (1)	1,050	6,948
6	Manchester (1)	1,048	7,996
7	Birmingham (1)	1,000	8,996
8	Liverpool (1)	939	9,935
9	Tyneside (1)	619	10,554
10	Birmingham (2)	506	11,060
11	Sheffield (1)	500	11,560
12	West Riding (1)	500	12,060
13	Bristol	490	12,550
14	Birmingham (3)	482	13,032
15	Edinburgh	460	13,492
16	Manchester (2)	450	13,942
17	Manchester (3)	450	14,392
18	London (5)	432	14,824
19	London (6)	430	15,254
20	Nottingham	406	15,660
21	London (7)	404	16,064
22	London (8)	404	16,468
23	Glasgow (2)	387	16,855
24	Tyneside (2)	384	17,239
25	West Riding (2)	380	17,619
26	Stoke-on-Trent	350	17,969
27	Hull	330	18,299
28	Leicester	322	18,621
29	Portsmouth	300	18,921
30	Tees (1)	296	19,217
31	West Riding (3)	290	19,507
32	Coventry	280	19,787
33	Cardiff	275	20,062
34	London (9)	267	20,329
35	Liverpool (2)	263	20,592
36	West Riding (4)	260	20,852
37	London (10)	252	21,104
38	Brighton	250	21,354
39	Blackburn	238	21,592
40	Plymouth	230	21,822
41	Wigan	227	22,049
42	Bournemouth	225	22,274
43	Southampton	220	22,494
44	Blackpool	205	22,699
45	Sheffield (2)	204	22,903

TABLE 10

CASUALTIES FOR DIFFERENT EVACUATION POLICIES

(Aiming Points as Table 9)

Bomb No.	Killed (cumulative total in 1000's)			Seriously injured (cumulative total in 1000's)		
	No Evacuation	45% Evacuation	100% Evacuation	No Evacuation	45% Evacuation	100% Evacuation
1	2,677	1,498	9	1,404	759	141
2	3,478	1,667	22	1,372	1,178	218
3	5,133	2,836	74	1,557	1,085	685
4	6,414	3,525	80	1,118	709	478
5	7,479	4,193	162	1,482	942	573
6	8,422	4,782	207	2,441	1,420	628
7	9,585	5,430	241	2,870	1,765	783
8	10,731	6,006	242	3,279	2,081	801
9	11,545	6,431	242	3,393	2,165	801
10	12,216	6,729	265	3,567	2,392	969
11	12,618	7,044	436	3,384	2,363	1,189
12	13,191	7,345	439	3,616	2,569	1,313
13	13,710	7,685	668	3,740	2,746	1,528
14	14,203	8,012	687	3,550	2,610	1,530
15	14,698	8,305	764	3,604	2,669	1,561
16	15,377	8,502	790	2,956	2,520	1,626
17	15,752	8,837	817	3,038	2,561	1,656
18	15,813	9,067	862	3,527	2,857	1,917
19	17,325	9,536	911	2,426	2,676	1,971
20	17,735	9,793	963	2,563	2,818	1,980
21	17,930	9,974	1,099	2,633	2,887	2,027
22	18,507	10,339	1,214	2,476	2,891	2,120
23	18,871	10,493	1,242	2,379	2,801	2,127
24	18,968	10,508	1,242	2,442	2,901	2,135
25	19,360	10,766	1,253	2,481	2,924	2,155
26	19,703	11,181	1,721	2,772	3,160	2,384
27	20,043	11,372	1,757	2,789	3,185	2,398
28	20,370	11,597	1,864	2,833	3,281	2,524
29	20,707	11,861	2,005	2,900	3,348	2,592
30	21,051	12,056	2,099	2,931	3,424	2,632
31	21,444	12,323	2,217	3,156	3,619	2,796
32	21,516	12,442	2,349	3,158	3,607	2,824
33	21,817	12,630	2,426	3,230	3,713	2,921
34	22,063	12,783	2,485	3,233	3,917	3,178
35	22,268	12,940	2,488	3,157	3,837	3,196
36	22,476	13,053	2,592	3,183	3,956	3,356
37	22,625	13,194	2,762	3,068	3,866	3,262
38	22,924	13,671	3,440	3,165	4,015	3,502
39	23,241	14,026	3,837	3,272	4,121	3,506
40	23,487	14,178	3,886	3,299	4,161	3,543
41	23,855	14,380	3,896	3,241	4,134	3,552
42	24,122	14,816	4,525	3,311	4,242	3,702
43	24,366	14,981	4,593	3,356	4,301	3,781
44	24,692	15,461	5,255	3,534	4,562	4,130
45	24,889	15,589	5,364	3,400	4,580	4,185

TABLE 11

AIMING POINTS AND CASUALTIES FOR WORST POSSIBLE ATTACK AFTER 100% EVACUATION

Bomb No.	Aiming Point	Cumulative total (1000's) Killed	Seriously injured
1	Brighton, Hove	749	55
2	Bournemouth, Poole	1,332	216
3	Blackpool, Lytham St. Annes, Cleveleys	1,977	940
4	Stoke-on-Trent, Newcastle-under-Lyme	2,424	1,190
5	Dundee, Tayport, Newport, Monifieth	2,865	1,204
6	Aberdeen	3,294	1,216
7	Rhondda, Merthyr Tydfil, Pontypool	3,860	1,617
8	Southend	4,232	1,660
9	Burnley, Nelson, Calne	4,653	1,560
10	Rhondda, Merthyr Tydfil, Pontypool	5,076	1,372
11	Gloucester, Cheltenham	5,338	1,772
12	Blackburn, Accrington, Oswaldthistle	5,746	1,503
13	Luton	6,183	1,757
14	Reading	6,719	2,107
15	Mansfield, Sutton (Kirkby) in Ashfield	7,115	2,200
16	Norwich	7,592	2,236
17	Watford, St. Albans, Hemel Hempstead	7,844	2,569
18	Northampton	8,218	2,737
19	Oxford	8,571	2,806
20	York	8,867	2,911
21	Farnborough, Aldershot	9,341	3,193
22	Ipswich	9,633	3,209
23	Slough, Windsor, Maidenhead	9,923	3,236
24	Rhondda, Merthyr Tydfil, Pontypool	9,950	3,446
25	Kirkcaldy, Cowdenbeath, Lockgelly	10,132	3,578
26	Easington, Seaham, Hatton	10,320	3,665
27	Worthing, Littlehampton	10,560	3,710
28	Egham, Staines, Chertsey	10,695	3,700
29	Torquay, Teignmouth, Paignton	10,880	3,750
30	Guildford	11,024	3,854
31	Bishop Auckland, Durham, Shildon	11,289	3,992
32	Margate, Broadstairs, Ramsgate	11,507	4,018
33	Lancaster, Morecombe, Heysham	11,753	4,129
34	Preston, Fulwood, Walton Le Dale	11,845	4,117
35	Darlington	12,098	4,206
36	Maidstone, Rochester, Chatham, Gillingham	12,369	4,487
37	Bath	12,693	4,588
38	Rhondda, Merthyr Tydfil, Pontypool	12,910	4,518
39	Burton-on-Trent, Swadlingcote	13,297	4,715
40	Folkestone, Dover	13,466	4,755
41	Swansea, Neath, Port Talbot	13,795	4,894
42	Swindon	14,029	4,966
43	Cambridge	14,283	5,045
44	Kettering, Wellingborough, Higham Ferrars	14,472	5,079

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CD/SA 5. Corrigendum

The administrative areas of certain British cities given in Table 12 were taken from the 1931 census, since when many of the cities have added appreciably to their areas. The following should therefore be substituted for Table 12.

County Borough	Administrative area (sq.miles)	Total density of attack (tons/sq.mile)
Hull	22.0	13.7
Sheffield	61.8	3.5
Portsmouth	14.4	18.0
Southampton	14.3	31.3
Bristol	38.2	30.0
Plymouth	14.9	33.0
Cardiff	22.0	4.5
Birmingham	80.0	6.9

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TABLE 13

Casualties with shelter and 45% evacuation

(Aiming points chosen to maximise blast casualties with no evacuation or shelter.)

Bomb No.	Aiming Point	Cumulative total (1000's) Killed	Cumulative total (1000's) Seriously injured
1	London (1)	38	0
2	London (2)	108	3
3	London (3)	176	23
4	London (4)	191	35
5	Glasgow (1)	298	66
6	Manchester (1)	363	76
7	Birmingham (1)	414	92
8	Liverpool (1)	472	92
9	Tyne (1)	511	92
10	Birmingham (2)	527	104
11	Sheffield (1)	652	147
12	West Riding (1)	698	178
13	Bristol (1)	800	241
14	Birmingham (3)	823	236
15	Edinburgh (1)	924	257
16	Manchester (2)	947	292
17	Manchester (3)	984	280
18	London (5)	1,009	294
19	London (6)	1,051	317
20	Nottingham (1)	1,111	329
21	London (7)	1,181	371
22	London (8)	1,249	410
23	Glasgow (2)	1,244	406
24	Tyne (2)	1,234	410
25	West Riding (2)	1,268	418
26	Stoke-on-Trent (1)	1,515	537
27	Hull (1)	1,566	544
28	Leicester (1)	1,656	578
29	Portsmouth (1)	1,750	622
30	Tees (1)	1,835	632
31	West Riding (3)	1,911	678
32	Coventry (1)	2,033	700
33	Cardiff (1)	2,080	716
34	London (9)	2,110	752
35	Liverpool (2)	2,096	752
36	West Riding (4)	2,171	830
37	London (10)	2,273	937
38	Brighton (1)	2,569	1,124
39	Blackburn (1)	2,824	1,208
40	Plymouth (1)	2,892	1,218
41	Wigan/St. Helens (1)	2,905	1,225
42	Bournemouth/Poole (1)	3,294	1,368
43	Southampton (1)	3,343	1,371
44	Blackpool (1)	3,641	1,536
45	Sheffield (2)	3,712	1,551

TABLE 14

CASUALTIES WITH SHELTER AND 45% EVACUATION

(Aiming points chosen to maximise casualties under these conditions)

Bomb No.	Aiming Point	Cumulative total (1000's)	
		Killed	Seriously injured
1	Brighton, Hove	445	91
2	Stoke-on-Trent, Newcastle-under-Lyme	718	206
3	Bournemouth, Poole	1,067	214
4	Aberdeen	1,387	224
5	Dundee, Tayport, Newport, Monifieth	1,612	264
6	Blackpool, Lytham St. Annes, Cleveleys	1,861	458
7	Southend	2,064	508
8	Blackburn, Accrington, Oswaldthistle	2,346	630
9	Rhondda, Merthyr Tydfil, Pontypool (1)	2,657	756
10	Burnley, Nelson, Calne	2,955	696
11	Norwich	3,233	750
12	Mansfield, Sutton (Kirkby) in Ashfield	3,459	778
13	Reading	3,738	875
14	Luton	3,974	949
15	Northampton	4,184	1,006
16	York	4,374	1,023
17	Rhondda, Merthyr Tydfil, Pontypool (2)	4,581	1,030
18	Oxford	4,779	1,070
19	Ipswich	4,966	1,087
20	Preston, Fulwood, Walton Le Dale	5,173	969
21	Watford, St.Albans, Hemel Hempstead	5,322	1,043
22	Farnborough, Aldershot	5,579	1,109
23	Bath	5,790	1,130
24	Gloucester, Cheltenham	5,889	1,202
25	Darlington	6,048	1,215
26	Margate, Broadstairs, Ramsgate	6,176	1,236
27	Maidstone, Rochester, Chatham, Gillingham	6,295	1,317
28	Egham, Staines, Chertsey	6,447	1,321
29	Worthing, Littlehampton	6,619	1,345
30	Swindon	6,767	1,363
31	Cambridge	6,927	1,374
32	Lancaster, Morecambe, Heysham	7,027	1,415
33	Swansea, Neath, Port Talbot	7,266	1,498
34	Slough, Windsor, Maidenhead	7,448	1,556
35	Torquay, Teignmouth, Paignton	7,543	1,583
36	Folkestone, Dover	7,639	1,604
37	Bishop Auckland, Durham, Shildon	7,755	1,705
38	Easington, Seaham, Hatton	7,839	1,733
39	Kirkcaldy, Cowdenbeath, Lockgelly	7,946	1,744
40	Burton-on-Trent, Swadlingcote	8,147	1,809
41	Guildford	8,215	1,840
42	Rhondda, Merthyr Tydfil, Pontypool (3)	8,315	1,859
43	Rhondda, Merthyr Tydfil, Pontypool (4)	8,484	1,868
44	Kettering, Wellingborough, Higham Ferrars	8,563	1,897

TABLE 17

EFFECT OF VARIATIONS IN THE ASSUMPTIONS

Case No	Remarks	Category of house damage	Duration of stay in refuge (hours)	Speed of transit out of contaminated area (miles per hr.)	Protective factor: % of houses	Protective factor: Factor	Total area of lethality (sq. miles)	Increase or decrease in area of lethality compared with case 1
1		Nil	48	20	15 10 55 20	150 70 30 10	181	-
		D	48	20	15 10 55 20	38 30 19 8		
		C	Optimum (5-24)	2	15 10 55 20	30 20 13 6		
		B	Optimum ($2\frac{1}{2}$-9)	2	15 10 55 20	10 8 6 3		
2	Reduced duration of stay	Nil	12	20	As Case 1		192	+ 6%
		D	12	20				
		C	1	2				
		B	1	2				
3	Reduced speed of transit	Nil	48	2	As Case 1		191	+ 6%
		D	48	2				
		C	Optimum	1				
		B	Optimum	1				
4	Reduced speed of transit and reduced duration of stay in B and C damaged areas	Nil	48	2	As Case 1		234	+ 29%
		D	48	2				
		C	1	1				
		B	1	1				
5	Most recent U.S. data on contour dimensions	All as Case 1					294	+ 62%
6	Improved fall-out protection	Nil	48	20	100	150	135	- 26%
		D	48	20	100	38		
		C	Optimum	2	100	30		
		B	Optimum	2	100	10		

APPENDIX

Let the dose rate in the open outside a shelter after 1 hour be Do r/hr.

Assume that fall-out all arrives at time T_1, and that the occupants leave the shelter (protective factor F) and cross the contaminated area at time T_2.

Assume that they move out of the contaminated area by the shortest route at a speed of v miles per hour, that the decay of dose with time during transit can be ignored, and that the dose rate falls off exponentially with distance, i.e.

$$D = Do\ T_2^{-1.2}\ e^{-kx}$$

Let d be the distance from the shelter to any given dose rate contour (say the 100 r/hr. at 1 hr. contour).

$$\text{Then } 100 = Do\ e^{-kd}$$

$$\text{i.e. } kd = \log e \left(\frac{Do}{100}\right) \quad \ldots\ldots\ldots\ldots \quad (1)$$

Let X be the "effective distance out of the contaminated area" such that the dose received in transit $= \frac{X}{v} Do\ T_2^{-1.2}$

$$\text{Then } X = \frac{1}{Do\ T_2^{-1.2}} \int_0^{\infty} D.dx$$

$$= \int_0^{\infty} e^{-kx} dx = \frac{1}{k}$$

$$= \frac{d}{\log e \left(\frac{Do}{100}\right)} \quad \text{from (1)}$$

$$\text{Therefore transit dose} = \frac{d}{v} \frac{Do\ T_2^{-1.2}}{\log e \left(\frac{Do}{100}\right)} \quad \ldots\ldots\ldots\ldots \quad (2)$$

Now total dose (dose in shelter plus transit dose)

$$= \frac{5\ T_1\ Do\ T_1^{-1.2} - 5\ T_2\ Do\ T_2^{-1.2}}{F} + \frac{d}{v} \frac{Do\ T_2^{-1.2}}{\log e \left(\frac{Do}{100}\right)} \quad \ldots\ldots\ldots\ldots \quad (3)$$

Differentiating with respect to T_2 to find the optimum time to leave

$$\frac{Do\ T_2^{-1.2}}{F} - 1.2 \frac{d}{v} \frac{Do\ T_2^{-2.2}}{\log e \left(\frac{Do}{100}\right)} = 0$$

$$\text{Therefore } T \text{ (opt.)} = \frac{1.2\ F}{\log e \left(\frac{Do}{100}\right)} \frac{d}{v} \quad \ldots\ldots\ldots\ldots \quad (4)$$

In practice, for people in houses, F is shown in paras. 7-10 to vary between about 150 and 5. In the critical area where people are on the verge of being killed or injured, d will usually lie between 2 and 4 miles. For transit on foot at 2 miles per hour we therefore find that the optimum time to leave the shelter will lie between 3 hours and 1 week.

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IDEALIZED LOCAL CONTOURS
FOR RESIDUAL RADIATION

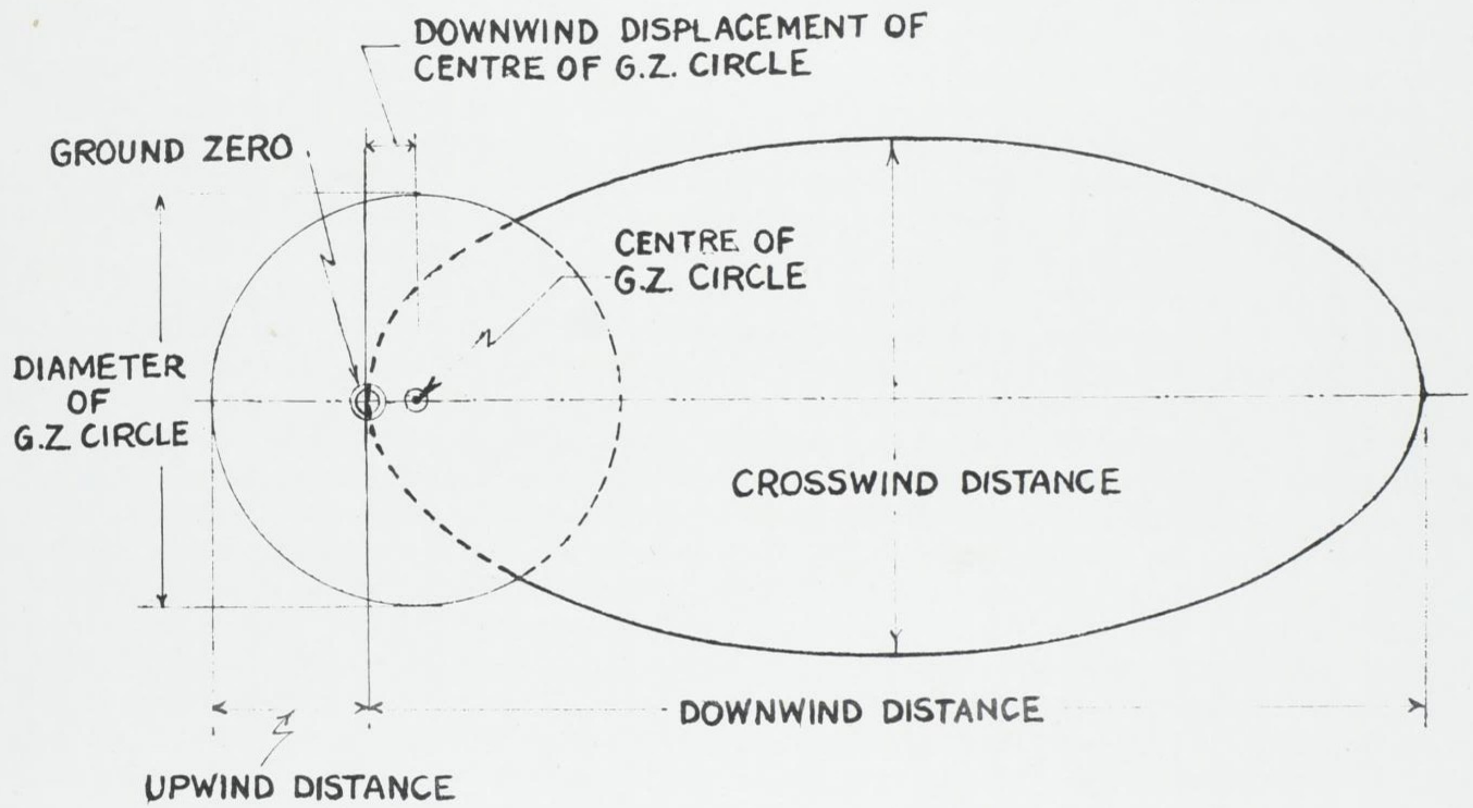

FIG. 1

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LETHALITY CONTOURS IN FALL-OUT AREA (HOUSES)

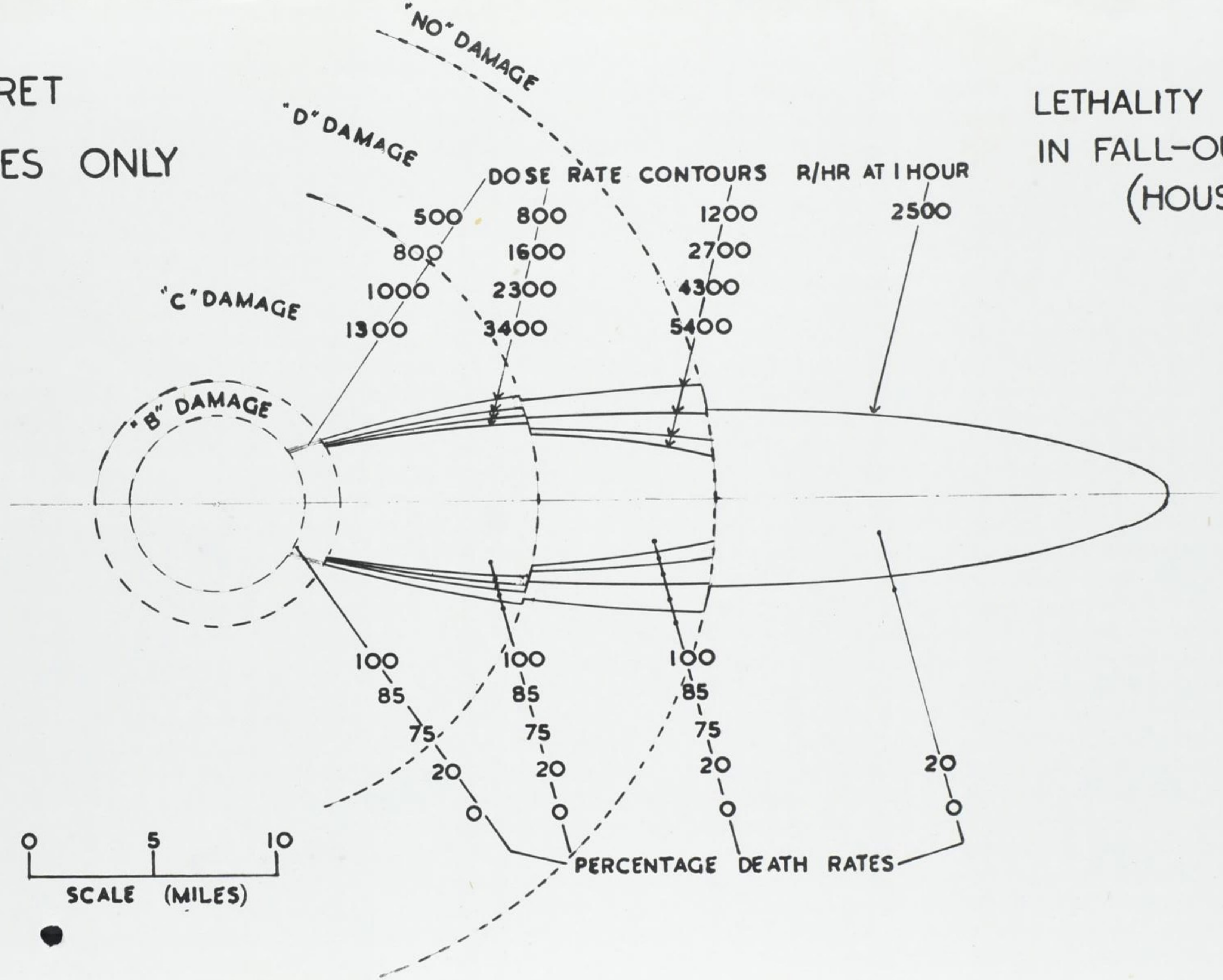

FIG. 2

COMBINED BLAST AND FALL-OUT LETHALITY ENVELOPES AROUND GROUND ZERO

(HOUSES)

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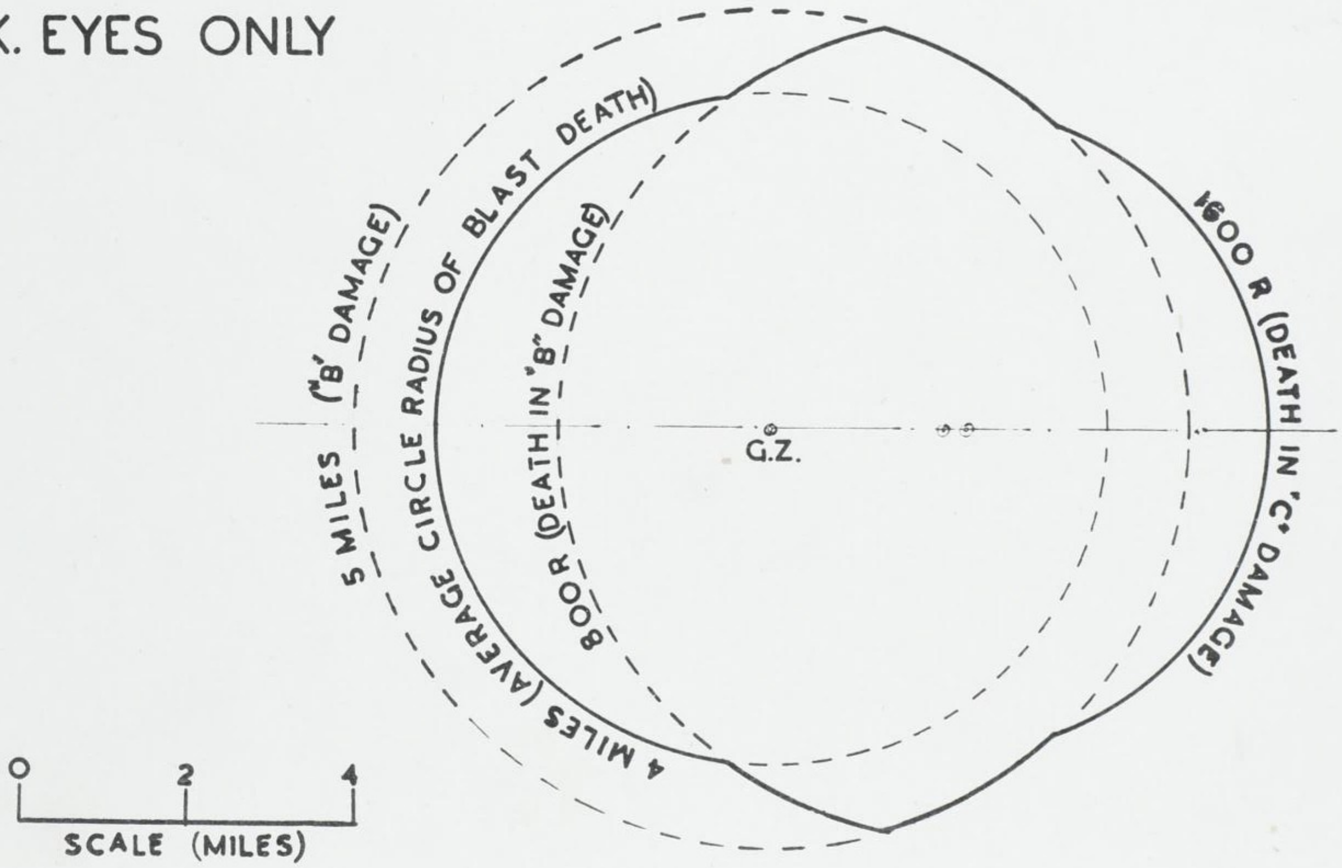

FIG. 3

COMBINED BLAST AND FALL-OUT SICKNESS ENVELOPES AROUND GROUND ZERO

(HOUSES)

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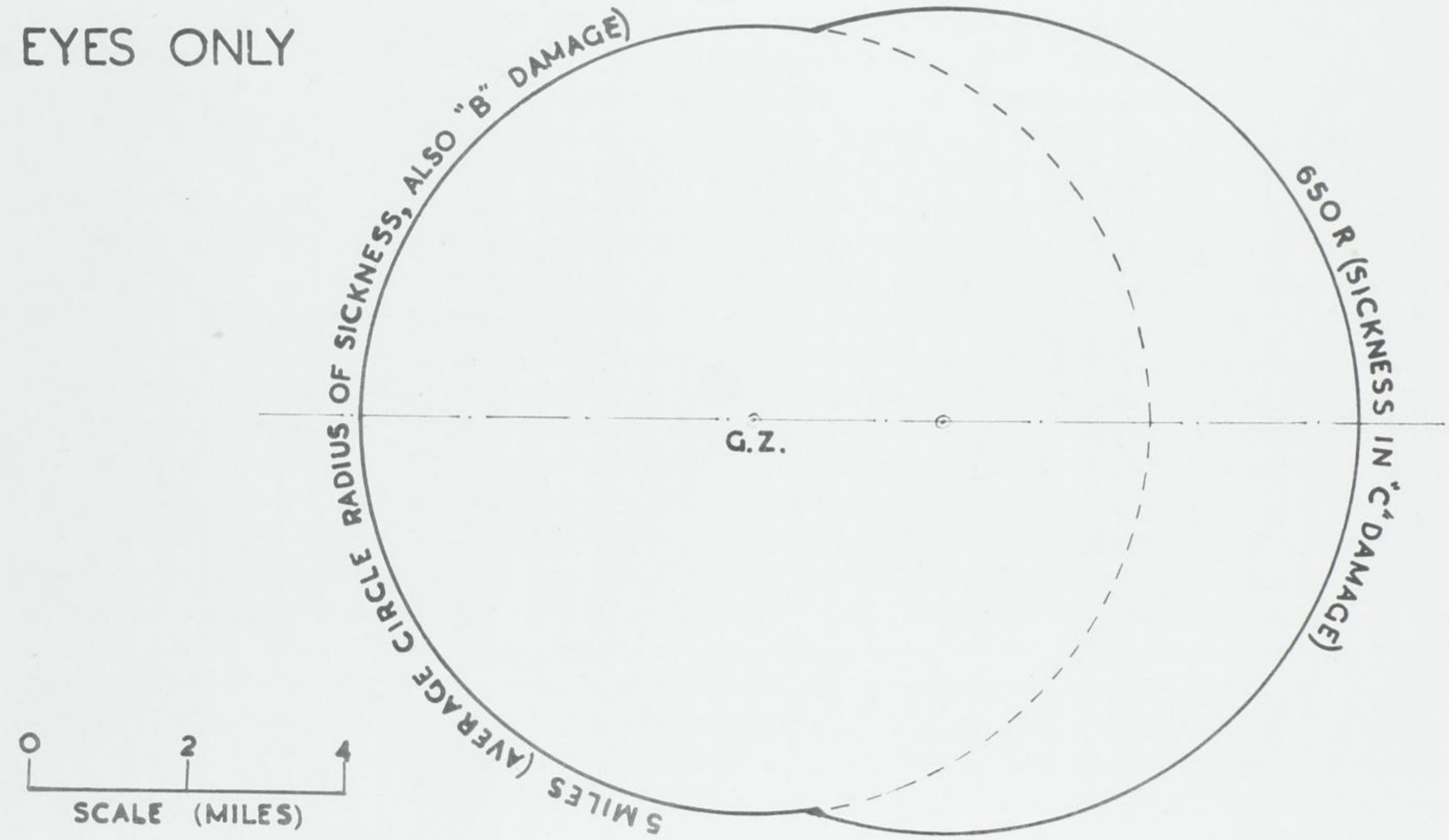

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FIG. 4

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OVERALL ENVELOPE FOR KILLED (HOUSES)

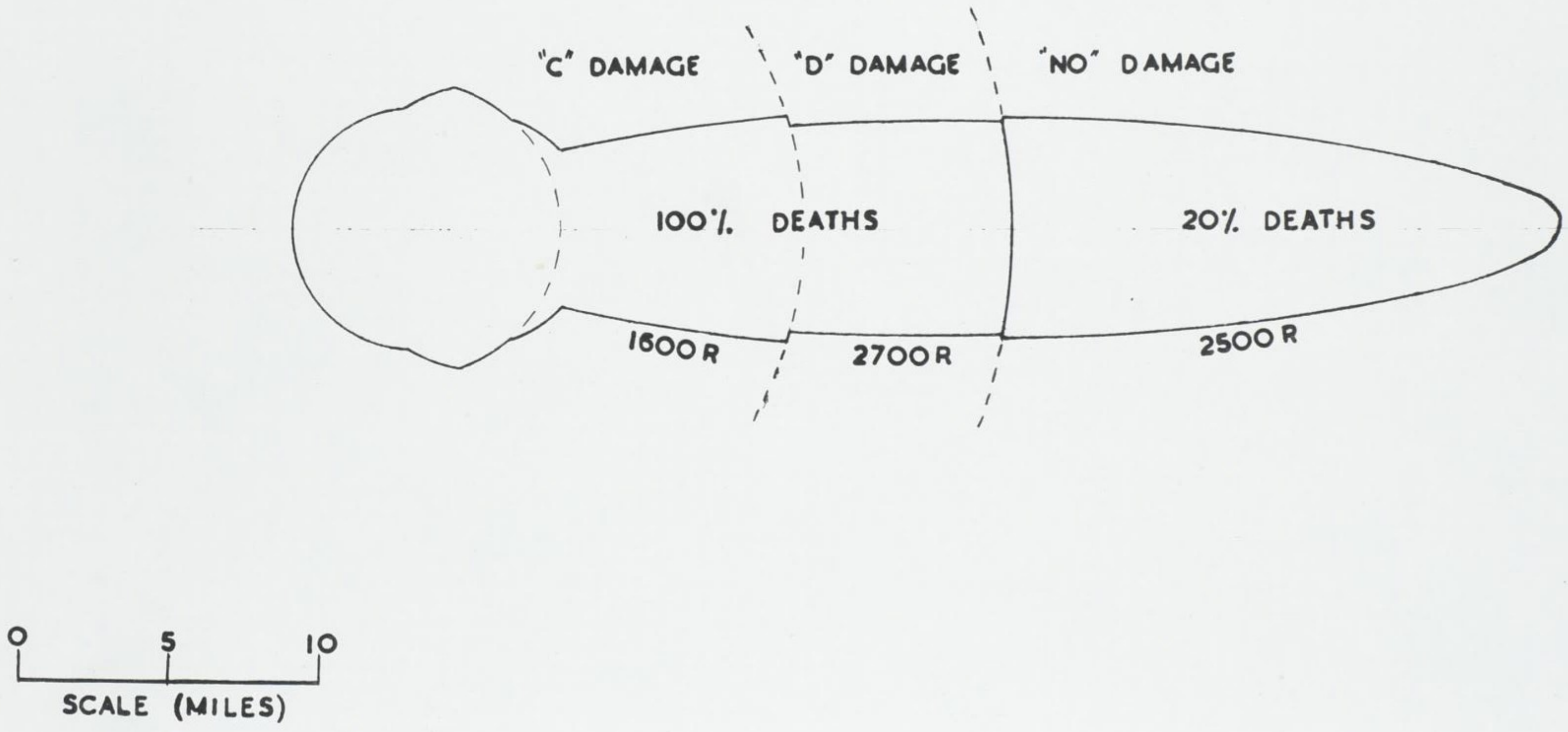

FIG. 5

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OVERALL ENVELOPE FOR KILLED AND SERIOUSLY INJURED (HOUSES)

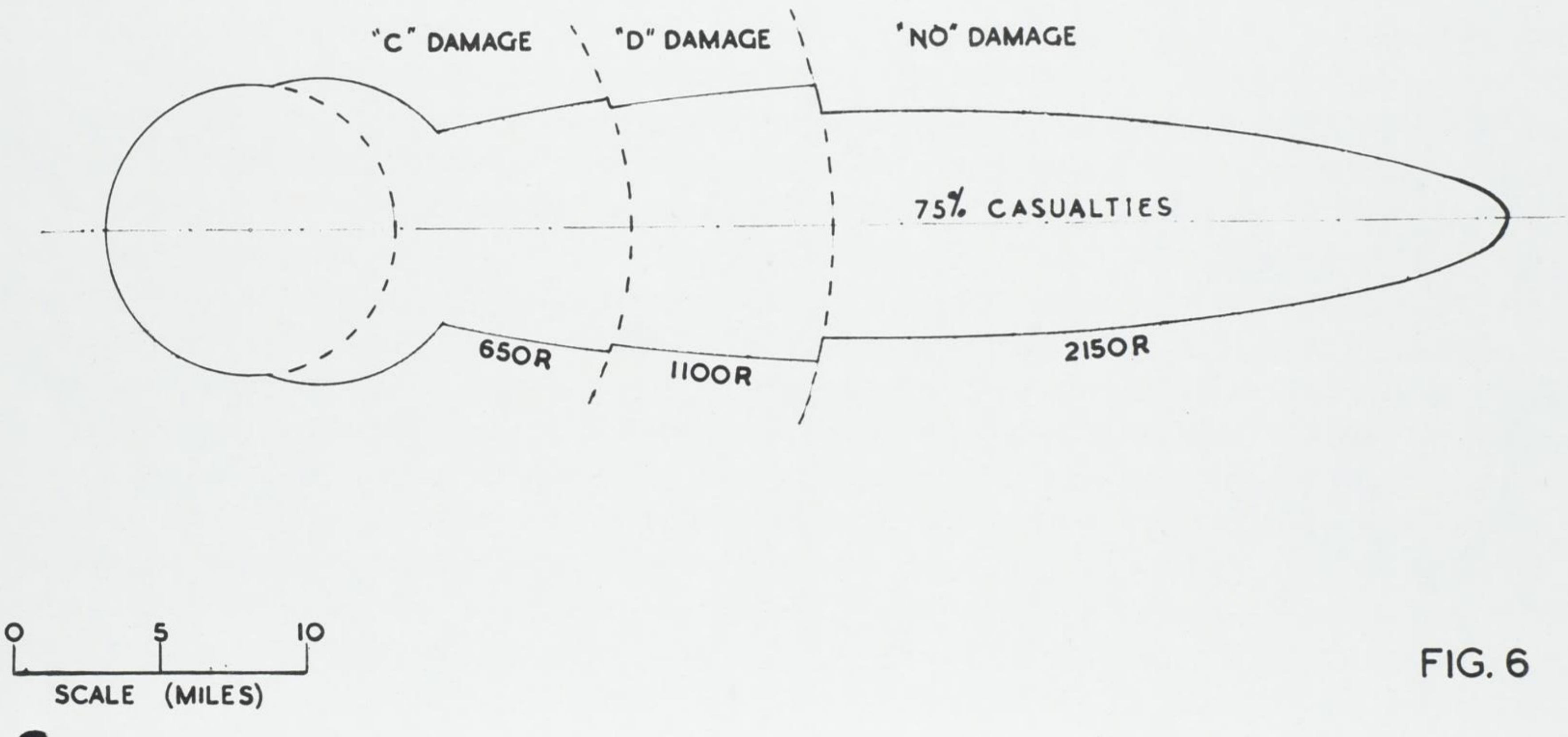

FIG. 6

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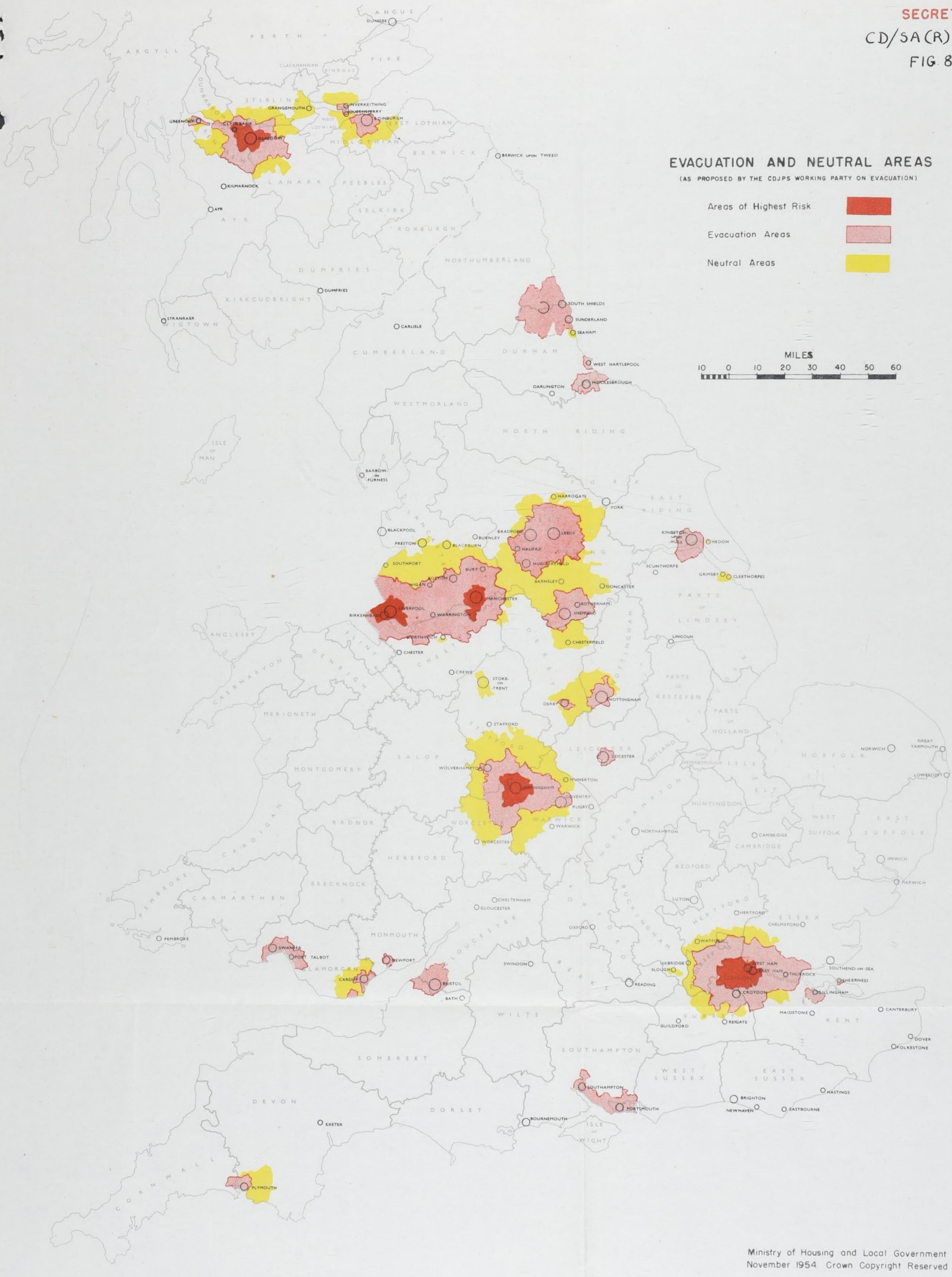
CD/SA(R)5

FIG. 8.



EVACUATION AND NEUTRAL AREAS

(AS PROPOSED BY THE CDJPS WORKING PARTY ON EVACUATION)

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TOTAL CASUALTIES FOR DIFFERENT EVACUATION POLICIES

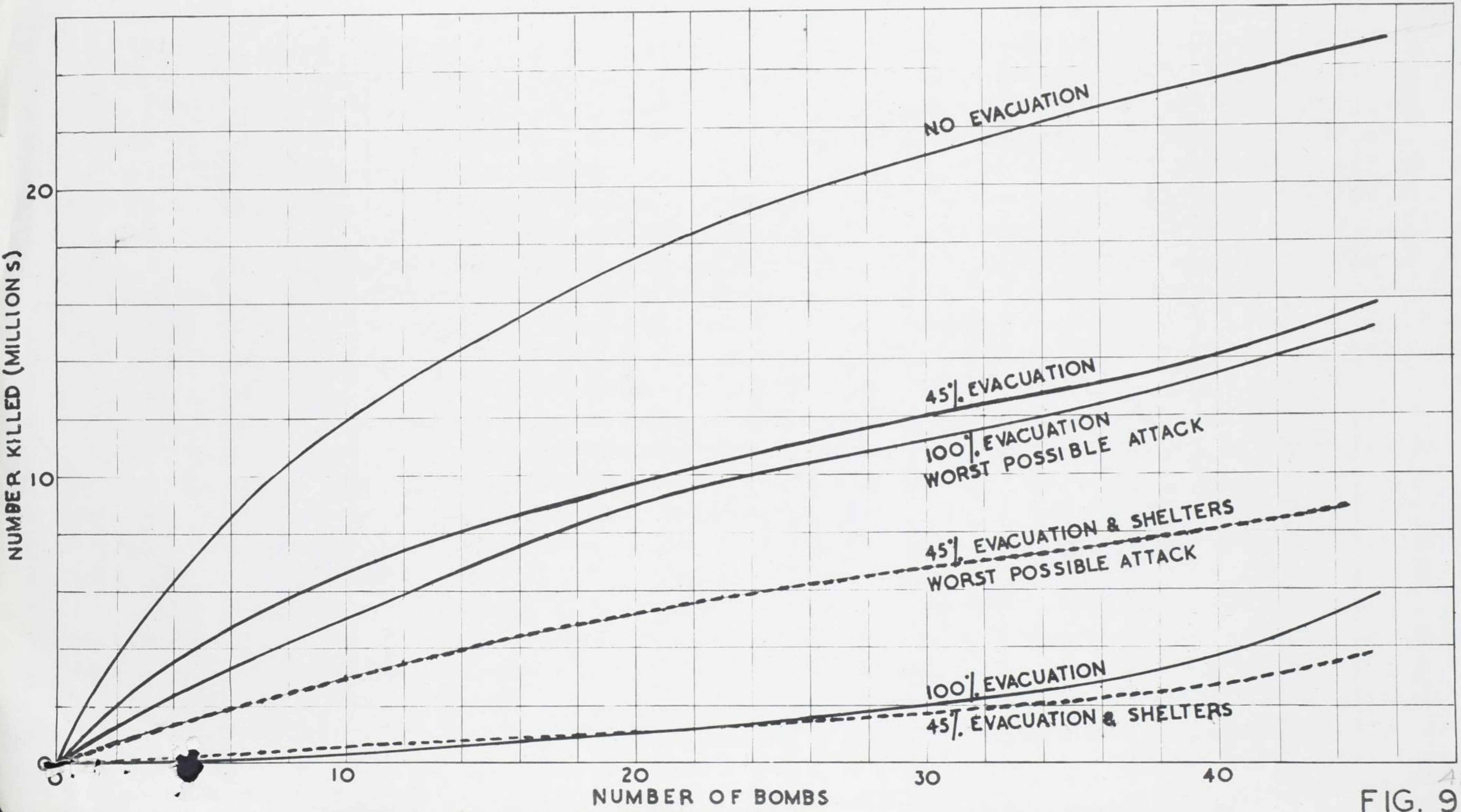

FIG. 9

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OVERALL ENVELOPE FOR KILLED
(FALL-OUT SHELTERS)

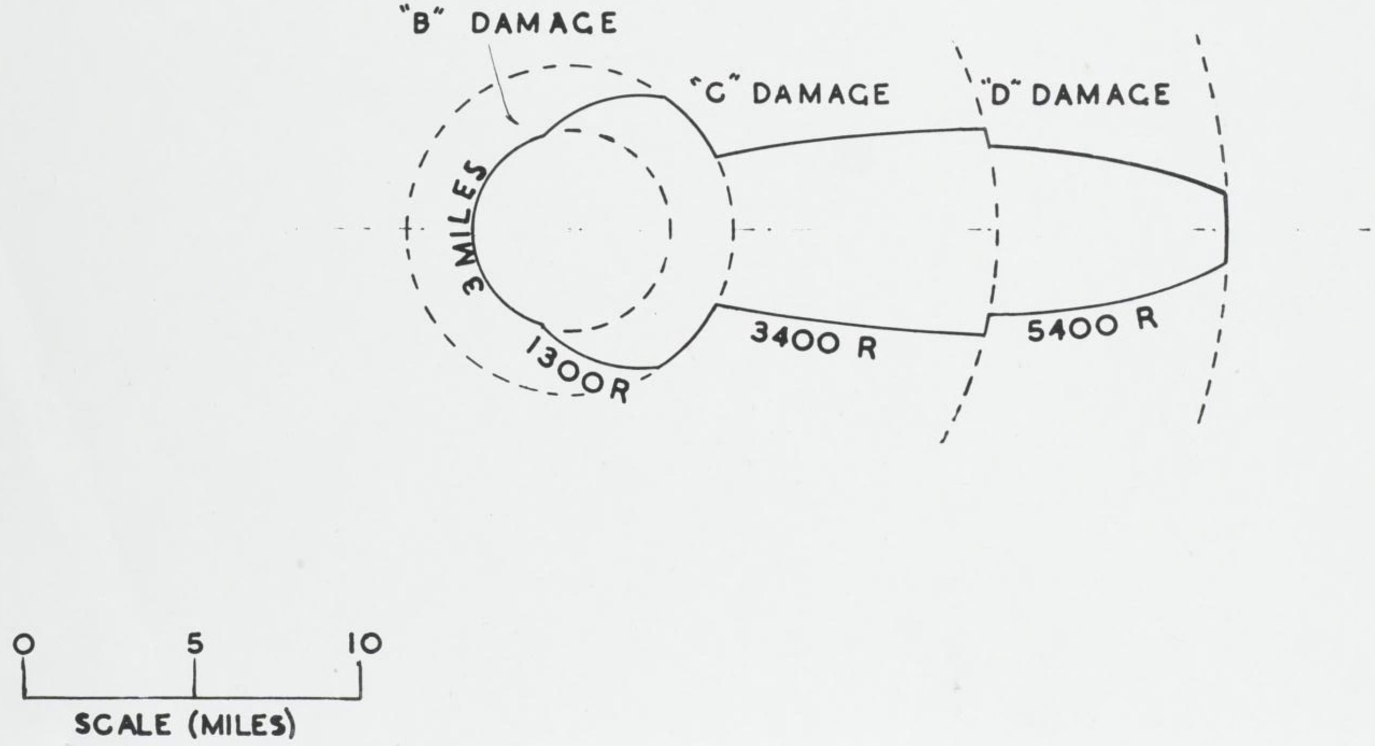

FIG. 10

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OVERALL ENVELOPE FOR KILLED PLUS SERIOUSLY INJURED.

(FALL-OUT SHELTERS)

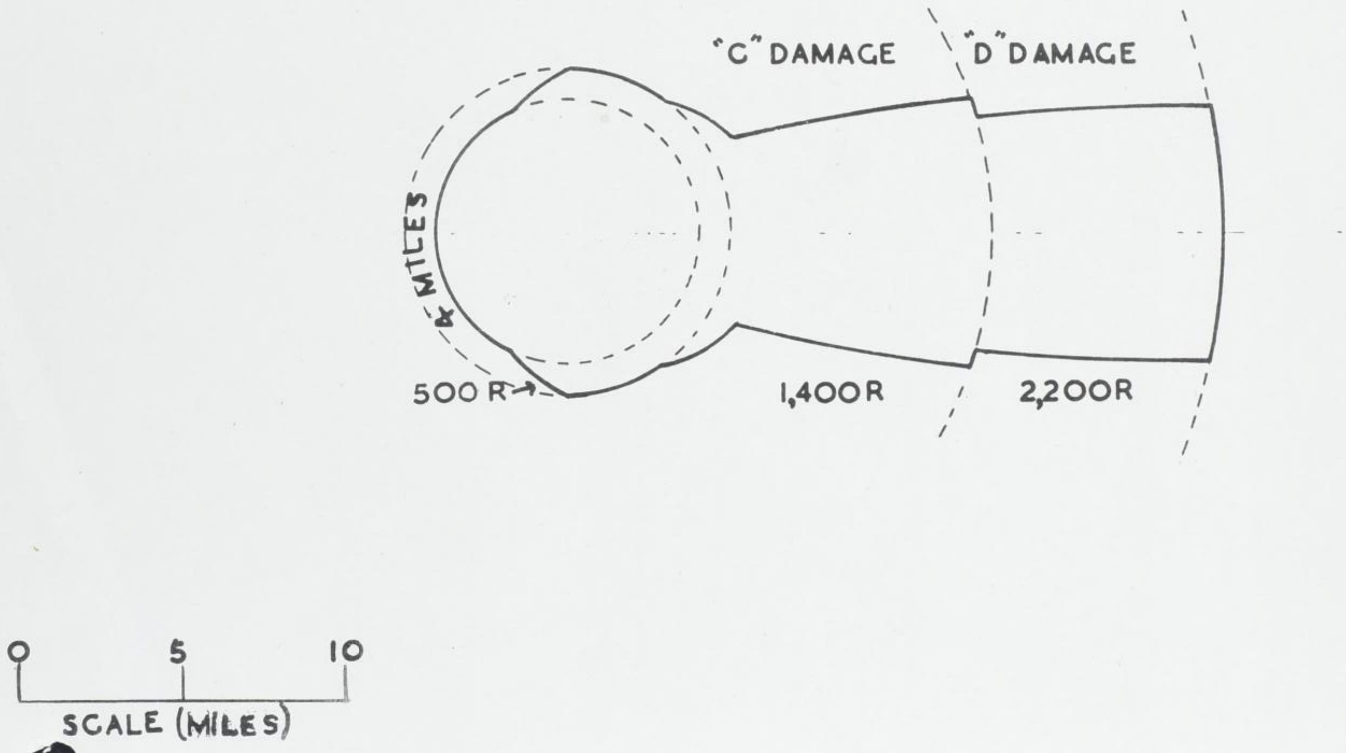

FIG. 11

E.R.

SECRET CD/SA(R)5(ADDENDUM)

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HOME OFFICE,

SCIENTIFIC ADVISERS BRANCH

Casualty Estimates for Ground Burst 10 Megaton Bombs

1. Introduction

At the request of

the scope of CD/SA(R)5 has been extended to include a further shelter and evacuation policy, namely the provision of the high grade tunnel shelters for every one living in evacuation areas but with no evacuation.

2. Summary

For any weight of attack up to 40 bombs, aimed to cause maximum casualties on the population not provided with shelter or evacuation facilities, the saving in fatal casualties with this new policy is shown to be slightly less ~~with this policy~~ than with the same shelter conditions but with evacuation of the priority classes (45%). However the saving in Seriously Injured would be somewhat greater. For greater weights of attack, when evacuation area targets are used up and more bombs are directed onto the neutral and reception areas, the saving in fatal casualties will now be slightly greater, as is to be expected.

3. Again if the enemy switched his attack to give the worst casualties possible the saving in fatal casualties and seriously injured would ~~this time~~ now be definitely greater for any weight of attack. ~~as also would be the saving in seriously injured.~~

4. Assuming the enemy to use a mixture of both attacks in approximately equal proportions, then the saving in fatal casualties will be slightly higher and the saving of seriously injured definitely higher for any weight of attack up to at least 45 bombs. ~~Against this stands~~ must be weighed the fact that almost ~~double~~ of course the number of tunnel shelters ~~would have~~ required to be constructed in the evacuation areas, would be almost doubled

5. Casualty Estimates

Using the same method and the same death and sickness envelopes as described in CD/SA(R)5, Paragraph 33 and Table 12, but with a non-evacuated population and with order of bombs as shown in Table 9, casualties now become as in Table 1 of the addendum. Comparison with Table 13, CD/SA(R)5 substantiates what has been said in the summary.

6. The saving in seriously injured is due to these casualties occurring largely much farther away from the target area and out in the reception areas where the population density has not been augmented by evacuation, whereas the killed occur mainly in the evacuation areas where the population density has not been reduced ~~by evacuation~~.

7. Casualties arising from the worst possible attack are listed in Table 2 of the addendum and this is to be compared ~~similarly~~ with Table 14, CD/SA(R)5. The definite saving in both fatal casualties and seriously injured for any weight of attack is due to both these types of casualty occurring, in this case, largely in the reception areas.

8. Tables 3 and 4 are in effect Tables 15 and 16, CD/SA(R)5 extended to compare the saving in fatal casualties of the four policies which have now been considered. ~~and supports quantitively what has already been said in the summary~~. Table 3 shows that there is very little difference in the saving of fatal casualties over the policies of the last 3 columns, but in Table 4 there is a very definite extra saving when using the policy of Tunnel shelter and no evacuation. This extra saving being in excess of 10%, up to at least a 30 bomb attack, over the next best policy.

E.R.

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TABLE 1

Casualties with shelter and no evacuation

(Aiming points chosen to maximise blast casualties with no evacuation or shelter)

	Bomb No.	Aiming Point	Cumulative Total (1000's)	
			Killed	Seriously Injured
	1	London (1)	100	0
110	2	London (2)	210	0
55	3	London (3)	265	15
30	4	London (4)	295	15
160	5	Glasgow (1)	455	30
95	6	Manchester (1)	550	40
90	7	Birmingham (1)	640	50
105	8	Liverpool (1)	745	50
70	9	Tyne (1)	815	50
30	10	Birmingham (2)	845	75
130	11	Sheffield (1)	975	105
70	12	West Riding (1)	1,045	125
95	13	Bristol (1)	1,140	160
15	14	Birmingham (3)	1,155	175
125	15	Edinburgh (1)	1,280	195
10	16	Manchester (2)	1,290	230
20	17	Manchester (3)	1,310	250
40	18	London (5)	1,350	255
30	19	London (6)	1,380	275
75	20	Nottingham (1)	1,455	280
	21	London (7)	1,520	305
	22	London (8)	1,585	330
	23	Glasgow (2)	1,510	335
	24	Tyne (2)	1,460	335
	25	West Riding (2)	1,520	335
	26	Stoke on Trent (1)	1,770	395
	27	Hull (1)	1,845	400
	28	Leicester (1)	1,945	415
	29	Portsmouth (1)	2,045	435
	30	Tees (1)	2,140	440
	31	West Riding (3)	2,235	480
	32	Coventry (1)	2,340	485
	33	Cardiff (1)	2,395	495
	34	London (9)	2,420	510
	35	Liverpool (2)	2,415	510
55	36	West Riding (4)	2,470	555
	37	London (10)	2,540	605
	38	Brighton (1)	2,790	685
	39	Blackburn (1)	3,025	710
90	40	Plymouth (1)	3,115	720
	41	Wigan/St.Helens (1)......	3,135	725
	42	Bournemouth/Poole (1) ...	3,365	765
	43	Southampton (1)	3,420	770
	44	Blackpool (1)	3,580	895
45	45	Sheffield (2)	3,625	910

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TABLE 2

Casualties with shelter and no evacuation

(Aiming points chosen to maximise casualties under these conditions)

Bomb No.	Aiming Point	Cumulative total 1000's	
		Killed	Seriously Injured
1	Stoke on Trent, Newcastle-under-Lyne	250	80
2	Brighton, Hove	500	150
3	Bournemouth, Poole	730	175
4	Aberdeen	920	190
5	Blackburn, Accrington, Oswaldthistle	1,155	255
6	Dundee, Tayport, Newport, Monifieth	1,345	260
7	Blackpool, Lytham St. Annes, Cleveleys	1,525	430
8	Southend	1,680	440
9	Preston, Fulwood, Walton-le-Dale	1,815	340
10	Glasgow	1,975	360
11	Rhondda, Merthyr Tydfil, Pontypool (1)	2,145	490
12	Burnley, Nelson, Colne	2,265	560
13	Swansea, Neath, Port Talbot	2,445	655
14	Norwich	2,595	700
15	Mansfield, Sutton (Kirkby) in Ashfield	2,730	740
16	Reading	2,910	795
17	Luton	3,080	820
18	Watford, St. Albans, Hemel Hempstead	3,190	890
19	Northampton	3,315	910
20	York	3,435	920
21	Oxford	3,565	930
22	Ipswich	3,680	940
23	Liverpool	3,785	940
24	Farnborough, Aldershot	3,935	990
25	Gloucester, Cheltenham	4,000	1,040
26	Maidstone, Chatham, Rochester, Gillingham ...	4,065	1,105
27	Slough, Windsor, Maidenhead	4,215	1,145
28	London (1)	4,315	1,145
29	London (2)	4,415	1,145
30	Bath	4,545	1,165
31	Margate, Broadstairs, Ramsgate	4,630	1,175
32	Egham, Staines, Chertsey	4,740	1,180
33	Darlington	4,840	1,190
34	Lancaster, Morecambe, Heysham	4,905	1,220
35	Edinburgh	5,030	1,245
36	Cambridge	5,125	1,250
37	Birmingham	5,215	1,265
38	Worthing, Littlehampton	5,320	1,260
39	Swindon	5,405	1,270
40	Leicester	5,505	1,280
41	Burton on Trent, Swadlincote	5,620	1,345
42	Rhondda, Merthyr Tydfil, Pontypool (2)	5,750	1,375
43	Bishop Auckland, Durham, Shildon	5,855	1,405
44	Easington, Seaham, Hatton	5,915	1,410
45	Torquay, Teignmouth, Paignton	5,970	1,430

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TABLE 3

Saving in fatal casualties with various shelter and evacuation policies (attack on centres of population)

No. of Bombs	Percentage saving in killed			
	45% evacuation	100% evacuation	45% evacuation and shelter	No evacuation and shelter
5	44	98	96	94
10	44	98	96	93
15	44	95	94	91
20	44	94	94	92
30	43	90	91	90
40	40	84	88	87

TABLE 4

Saving in fatal casualties with various shelter and evacuation policies (worst possible attack)

No. of Bombs	Percentage saving in killed		
	100% evacuation	45% evacuation and shelter	No evacuation and shelter
5	62	79	85
10	58	76	84
15	52	72	81
20	50	71	80
30	47	68	78
40	44	65	77